G5RV MULTIBAND ANTENNA... UP-TO-DATE

by Louis Varney, CEng, MIEE, AIL, G5RV*

Louis Varney became interested in "wireless" in 1922 when 11 years old. Obtained "artificial aerial" licence 2ARV in 1928, then G5RV in 1929. DXCC No 64 in 1932. Founder member, FOC, 1947. Founder member, RAOTA (UK). Member RAOTC (Australia). Member of RSGB Council mid-'sixties. Author of many articles published by RSGB on tvi suppression, transmitter design and antenna systems. Designed G5RV multi-band antenna 1946. Joined Marconi W T Co Ltd, 1930. Served in Royal Corps of Signals during second world war. Consulting engineer (telecoms), 1960-76. Speaks and writes French, Spanish, Italian and Portuguese. Hobbies: amateur radio, oil painting, horse riding and haute cuisine (learned while working in Paris). Has visited or lived in some 75 countries and has held licences or operated as guest operator in 55. President-for-life, Mid-Sussex ARS.

THE G5RV ANTENNA, with its special feeder arrangement, is a multiband centre-fed antenna capable of very efficient operation on all hf bands from 3·5 to 28MHz, specifically designed with dimensions which allow it to be installed in gardens which can accommodate a reasonably-straight run of about 102ft (31·1m) for the "flat-top". However, because the most useful radiation from a horizontal or inverted-V resonant antenna takes place from the centre two-thirds of its total length, up to one-sixth of this total length at each end of the antenna may be dropped vertically, semi-vertically, or bent at some convenient angle to the main body of the antenna without significant loss of effective radiation efficiency. For installation in a very limited space, the dimensions of both the "flat-top" and the matching section can be divided by a factor of two to make the half-size G5RV, which is a very efficient antenna from 7 to 28MHz. The full-size G5RV will also function on the 1·8MHz band if the station end of the feeder (either balanced or coaxial-type) is strapped and fed by a suitable astu using a good earth connection or a counterpoise wire. Similarly, the half-size version may be used thus on the 3·5 and 1·8MHz bands.

In contradistinction to multiband antennas in general, the full-size G5RV antenna was *not* designed as a λ/2 dipole on the lowest frequency of operation, but as a 3λ/2 centre-fed long-wire antenna on 14MHz, where the 34ft (10·36m) open-wire matching section functions as a 1:1 impedance transformer, enabling the 75Ω twinlead or 50/80Ω coaxial cable feeder to "see" a close impedance match on that band with a consequently low vswr on the feeder. However, on all the other hf bands the function of this section is to act as a "make-up" section to accommodate that part of the standing-wave (current and voltage components) which, on certain of the operating frequencies, cannot be completely accommodated on the "flat-top" (or inverted-V) radiating portion. The design centre frequency for the full-size version is 14,150kHz, and the dimension of 102ft (31·1m) is derived from the formula for long-wire antennas which is:

$$\text{Length (ft)} = \frac{492\ (n - 0{\cdot}05)}{f\text{MHz}} = \frac{492 \times 2{\cdot}95}{14{\cdot}15} = 102{\cdot}57\text{ft}\ (31{\cdot}27\text{m})$$

where n = number of half-wavelengths of the wire (flat-top).
In practice, since the whole system will be brought to resonance by the use of an astu, the antenna is cut to 102ft (31·1m).

As it does not make use of traps or ferrite beads, the "dipole" portion becomes progressively longer in electrical length with increasing frequency. This effect confers certain advantages over a trap or ferrite-bead loaded dipole because, with increasing electrical length, the major lobes of the vertical component of the polar diagram tend to be lowered as the operating frequency is increased. Thus, from 14MHz up, most of the energy radiated in the vertical plane is at angles suitable for dx working. Furthermore, the polar diagram changes with increasing frequency from a typical λ/2 dipole pattern at 3·5MHz and a 2 × λ/2 in-phase pattern at 7 and 10MHz to that of a "long-wire" antenna at 14, 18, 21, 24 and 28MHz.

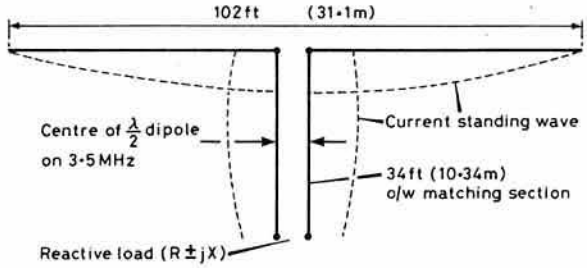

Fig 1. Current standing-wave distribution on the G5RV antenna and matching section at 3·5MHz. The antenna functions as a λ/2 dipole partially folded up at the centre

Although the impedance match for 75Ω twinlead or 80Ω coaxial cable at the base of the matching-section is very good on 14MHz, and even the use of 50Ω coaxial cable results in only about a 1·8:1 vswr on this band, the use of a suitable astu is necessary on all the other hf bands because, on those bands, the antenna plus the matching-section will present a *reactive* load to the feeder. Thus, the use of the correct type of astu (unbalanced input to balanced output if twin-wire feeder is used, or unbalanced to unbalanced if coaxial feeder is used) is essential in order to ensure the maximum transfer of power to the antenna from a typical transceiver having a 50Ω coaxial (unbalanced) output. Also to satisfy the stringent load conditions demanded by such modern equipment employing an alc system which "senses" the vswr condition presented to the solidstate transmitter output

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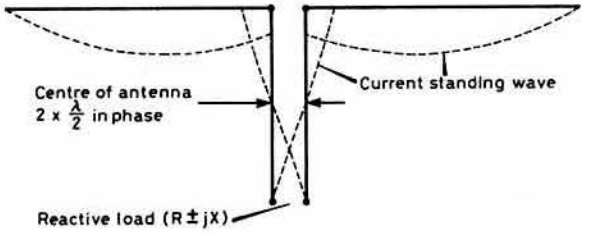

Fig 2. Current distribution on the antenna and matching section on 7MHz. The antenna now functions as a colinear array with two half-waves fed in phase

stage so as to protect it from damage which could be caused by a reactive load having a vswr of more than about 2:1[1].

The above reasoning does not apply to the use of the fullsize G5RV antenna on 1·8MHz, or to the use of the half-size version on 3·5 and 1·8MHz. In these cases the station end of the feeder conductors should be "strapped" and the system tuned to resonance by a suitable series-connected inductance and capacitance circuit connected to a good earth or counterpoise wire. Alternatively, an "unbalanced-to-unbalanced" type of astu such as a "T" or "L" matching circuit can be used[2]. Under these conditions the "flat-top" (or inverted-V) portion of the antenna plus the matching section and feeder function as a "Marconi" or "T" antenna, with most of the effective radiation taking place from the vertical, or near vertical, portion of the system; the "flat-top" acting as a top-capacitance loading element. However, with the system fed as described above, very effective radiation on these two bands is obtainable even when the "flat-top" is as low as 25ft (7·6m) above ground.

Theory of operation

The general theory of operation has been explained above; the detailed theory of operation on each band from 3·5 to 28MHz follows, aided by figures showing the current standing wave conditions on the "flat-top" and the matching (or make-up) section. The relevant theoretical horizontal plane polar diagrams for each band may be found in any of the specialized antenna handbooks. However, it must be borne in mind that: (a) the polar diagrams generally shown in two dimensional form are, in fact, three dimensional (ie solid) figures around the plane of the antenna; and (b) all theoretical polar diagrams are modified by reflection and absorption effects of near-by conducting objects such as wire fences, metal house guttering, overhead electric power and telephone wires, house electric wiring systems, house plumbing systems, metal masts and guy wires, and large trees. Also the local earth conductivity will materially affect the actual polar radiation pattern produced by an antenna. Theoretical polar diagrams are based on the assumptions that an antenna is supported in "free space" above a perfectly conducting ground. Such conditions are obviously impossible of attainment in the case of typical amateur installations. What this means in practice is that the reader should not be surprised if *any* particular antenna in a typical amateur location produces contacts in directions where a null is indicated in the theoretical polar diagram and perhaps not sucn effective radiation in the directions of the major lobes as theory would indicate.

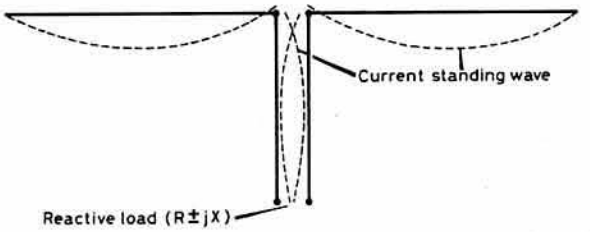

Fig 3. Current standing-wave distribution on the antenna and matching section on 10MHz. The antenna functions as a colinear array with two half-waves fed in phase

3·5MHz. On this band each half of the "flat-top" plus about 17ft (5·18m) of each leg of the matching-section forms a fore-shortened or slightly folded up λ/2 dipole. The remainder of the matching-section acts as an unwanted but unavoidable reactance between the *electrical* centre of the dipole and the feeder to the astu. The polar diagram is effectively that of a λ/2 antenna. See Fig 1.

7MHz. The "flat-top" plus 16ft (4·87m) of the matching section now functions as a partially-folded-up "two half-waves in phase" antenna producing a polar diagram with a somewhat sharper lobe pattern than a λ/2 dipole due to its colinear characteristics. Again, the matching to a 75Ω twinlead or 50/80Ω coaxial feeder at the base of the matching section is degraded somewhat by the unwanted reactance of the lower half of the matching section but, despite this, by using a suitable astu the system loads well and radiates very effectively on this band. See Fig 2.

10MHz. On this band the antenna functions as a two half-wave in-phase colinear array, producing a polar diagram virtually the same as on 7MHz. A reactive load is presented to the feeder at the base of the matching section but, as for 7MHz, the performance is very effective. See Fig 3.

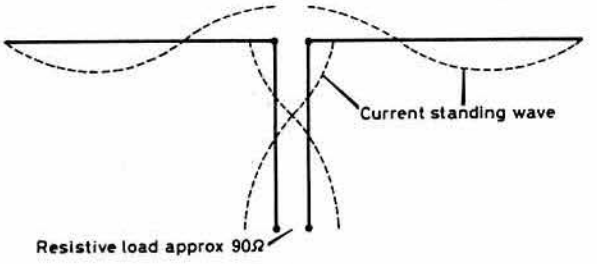

Fig 4. Current standing-wave distribution on the antenna and matching section on 14MHz. In this case the antenna functions as a centre-fed long-wire of three half-waves *out of phase*. The matching section now functions as a 1:1 impedance transformer, presenting a resistive load of approximately 90Ω at the lower end

14MHz. At this frequency the conditions are ideal. The "flat-top" forms a 3λ/2 long centre-fed antenna which produces a multi-lobe polar diagram with most of its radiated energy in the vertical plane at an angle of about 14°, which is very effective for dx working. Since the radiation resistance at the centre of a 3λ/2 long-wire antenna supported at a height of λ/2 above ground of average conductivity is about 90Ω, and the 34ft (10·36m) matching section now functions as a 1:1 impedance transformer, a feeder of anything between 75 and 80Ω characteristic impedance will "see" a non-reactive (ie resistive) load of about this value at the base of the matching section, so that the vswr on the feeder will be very nearly 1:1. Even the use of 50Ω coaxial feeder will result in a vswr of only about 1·8:1. It is here assumed that 34ft (10·36m) is a reasonable average antenna height in amateur installations. See Fig 4.

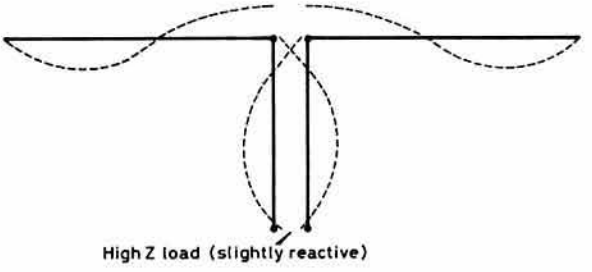

Fig 5. Current standing-wave distribution on the antenna and matching section on 18MHz. The antenna functions as two full-wave antennas, slightly folded up at the centre, fed in phase

18MHz. The antenna functions as two full-wave antennas fed in phase; combining the broadside gain of a two-element colinear array with somewhat lower zenithal angle radiation than a λ/2 dipole due to its long-wire characteristic. See Fig 5.

21MHz. On this band the antenna works as a "long-wire" of five half-waves, producing a multilobe polar diagram with very effective low zenithal angle radiation. Although a high resistive load is presented to the feeder at the base of the make-up section, the system loads very well when used in conjunction with a suitable astu and radiates very effectively for dx contacts. See Fig 6.

24MHz. The antenna again functions effectively as a 5λ/2 "long-wire" but, because of the shift in the positions of the current anti-nodes on the flat-top and the matching section, as may be seen from Fig 7, the matching or "make-up" section now presents a much lower resistive load condition to the feeder connected to its lower end than it does on 21MHz. Again, the polar diagram is multilobed with low zenithal angle radiation.

28MHz. On this band, the antenna functions as two "long-wire" antennas, each of three half-waves, fed in-phase. The polar diagram is similar to that of a 3λ/2 "long-wire" but with even more gain over a λ/2 dipole due to the colinear effect obtained by feeding two 3λ/2 antennas, in line and in close proximity, in-phase. See Fig 8.

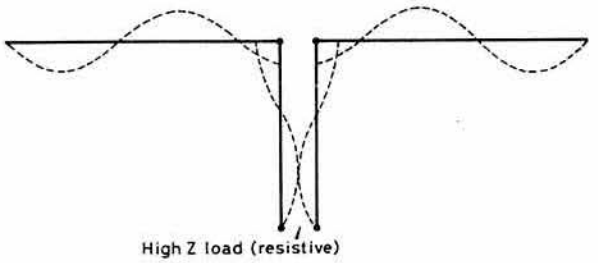

Fig 6. Current standing-wave distribution on the antenna and matching section on 21MHz. On this band the antenna works as a long-wire of five half-waves. The base of the matching section presents a virtually non-reactive high impedance load to the feeder

Construction

The antenna

The dimensions of the antenna and its matching section are shown in Fig 9. The "flat-top" should, if possible, be horizontal and run in a straight line, and should be erected as high as possible above ground. In describing the theory of operation, it has been assumed that it is generally possible to erect the antenna at an average height of about 34ft (10·36m), which happens to be the optimum height for the antenna at 14MHz. Although this is too low for optimum radiation efficiency on 1·8, 3·5 and 7MHz for *any* horizontal type of antenna, in practice few amateurs can install masts of the optimum height of half a wavelength at 3·5 or 7MHz, and certainly not at 1·8MHz.

If, due to limited space available, or to the shape of the garden, it is not possible to accommodate the 102ft (31·1m) top in a straight line, up to about 10ft (3m) of the antenna wire at each end may be allowed to hang vertically or at some convenient angle, or be bent in the horizontal plane, with little practical effect upon performance. This is because, for any resonant dipole antenna, most of the effective radiation takes place from the centre two-thirds of its length where the current antinodes are situated. Near to each end of such an antenna, the amplitude of the current standing wave falls rapidly to zero at the outer extremities; consequently, the effective radiation from these parts of the antenna is minimal.

The antenna may also be used in the form of an inverted-V. However, it should be borne in mind that, for such a configuration to radiate at maximum efficiency, the included angle at the apex of the V should not be less than about 120°[3]. The use of 14swg enamelled copper wire is recommended for the flat-top or V, although thinner gauges such as 16 or even 18swg can be used.

The matching section

This should be, preferably, of open-wire feeder construction for minimum loss. Since this section *always* carries a standing-wave of current (and voltage) its actual impedance is unimportant. A typical, and very satisfactory, form of construction is shown in Fig 10. The feeder spreaders may be made of any high-grade plastic strips or tubing; the clear plastic tubing sold for beer or wine syphoning is ideal.

If it is desired to use 300Ω ribbon type feeder for this section, it is strongly recommended that the type with "windows" be used because of its much lower loss than that with solid insulation throughout its length, and its relative freedom from the "detuning" effect caused by rain or snow. If this type of feeder is used for the matching section, allowance must be made for its velocity factor (vf) in calculating the mechanical length required to resonate as a half-wave section *electrically* at 14·15MHz. Since the vf of standard 300Ω ribbon feeder is 0·82, the *mechanical* length should be 28ft (8·5m). However, if 300Ω ribbon with "windows" is used, its vf will be almost that of open-wire feeder, say 0·90, so its *mechanical* length should be 30·6ft (9·3m). (300Ω ribbon feeder with "windows" is available from W. H. Westlake, Clawton, Holsworthy, Devon; Type BOFA GMP6.)

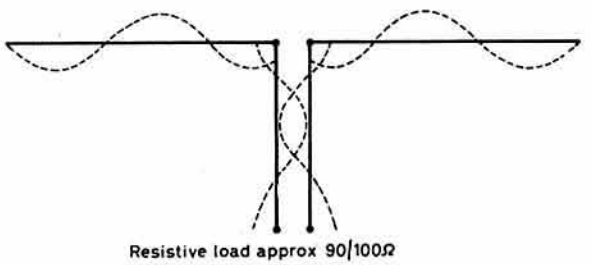

Fig 7. Current standing-wave distribution on the antenna and matching section on 24MHz. The antenna functions as a long-wire of five half-waves

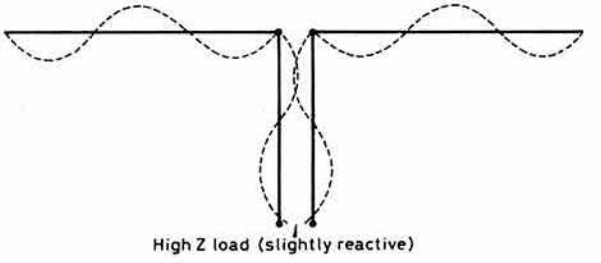

Fig 8. Current standing-wave distribution on the antenna and matching section on 28MHz. The antenna functions as two long-wire antennas each of three half-waves long, fed in phase. A very effective form of antenna giving good multi-lobe, low zenithal angle, radiation

This section should hang vertically from the centre of the antenna for at least 20ft (6·1m) or more if possible. It can then be bent and tied off to a suitable post with a length of nylon or terylene cord so as to be supported at above head-height to the point where, supported by a second post, its lower end is connected to the feeder.

The feeder

The antenna can be fed by any convenient type of feeder *provided always that a suitable type of astu is used.* In the original article describing the G5RV antenna, published in the, then, *RSGB Bulletin* November 1966, it was suggested that if a coaxial cable feeder was used, a balun might be employed to provide the necessary unbalanced-to-balanced transformation at the base of the matching section. This was because the antenna and its matching section constitute a *balanced* system, whereas a coaxial cable is an *unbalanced* type of feeder. However, later experiments and a better understanding of the theory of operation of the balun indicated that such a device was unsuitable because of the highly reactive load it would "see" at the base of the matching or "make-up" section on most hf bands.

It is now known that if a balun is connected to a reactive load presenting a vswr of more than about 2:1, its internal losses increase, resulting in heating of the windings and saturation of its core (if used). In extreme cases, with relatively high power operation, the heat generated due to the power dissipated in the device can cause it to burn out. However, the main reason for not employing a balun in the case of the G5RV antenna is that, unlike an astu which employs a *tuned circuit*, the balun cannot compensate for the reactive load condition presented to it by the antenna on most of the hf bands, whereas a suitable type of astu can do this most effectively and efficiently.

Recent experiments by the author to determine the importance or otherwise of "unbalance" effects caused by the direct connection of a coaxial feeder to the base of the matching section had a rather surprising result. They proved that, in fact, the hf currents measured at the junction of the inner conductor of the coaxial cable with one side of the (balanced) matching section and at the junction of the outer coaxial conductor (the sheath) with the other side of this section are virtually *identical* on all bands up to 28MHz, where a slight but inconsequential difference in these currents has been observed. There is, therefore, no need to provide an unbalanced-to-balanced device at this junction when using a coaxial feeder.

However, the use of an *unbalanced-to-unbalanced* type of astu between the coaxial output of a modern transmitter (or transceiver) and the coaxial feeder is essential because of the reactive condition presented at the station end of this feeder which, on all but the 14MHz band, will have a fairly high to high vswr on it. This vswr, however, will result in insignificant losses on a good-quality coaxial feeder of reasonable length; say, up to about 70ft (21·3m). Because it will, inevitably, have standing waves on it, the actual characteristic impedance of the coaxial cable is unimportant, so that either 50Ω or 80Ω type can be used.

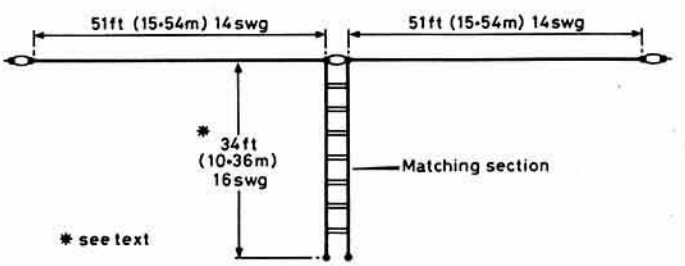

Fig 9. Construction dimensions of the G5RV antenna and matching section

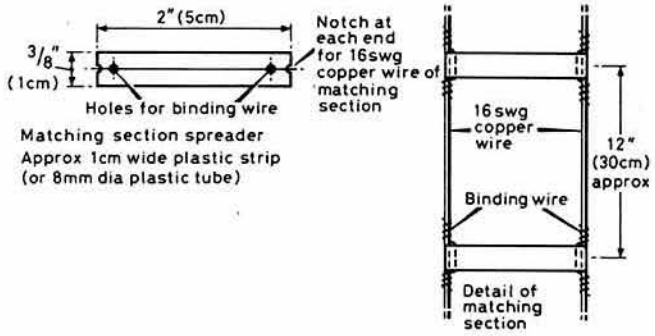
2" (5cm)
3/8" (1cm)
Notch at each end for 16swg copper wire of matching section
Holes for binding wire
Matching section spreader
Approx 1cm wide plastic strip
(or 8mm dia plastic tube)
16 swg copper wire
Binding wire
12" (30cm) approx
Detail of matching section

Fig 10. Constructional details of the matching section. Also suitable for open-wire feeder construction

Another very convenient type of feeder that may be used is 75Ω twinlead. However, because of the relatively high loss in this type of feeder at frequencies above about 7MHz, especially when it has a high vswr on it, it is recommended that not more than about 50 to 60ft (15·2 to 18·3m) of this type of feeder be used between the base of the matching section and the astu. Unfortunately the 75Ω twinlead available in the UK is the *receiver* type; the much less lossy *transmitter* type is available in the USA.

By far the most efficient feeder is the "open wire" type. A suitable length of such feeder can be constructed in exactly the same way as that described for the open-wire matching section. If this form of feeder is employed, almost any convenient length may be used from the centre of the antenna right to the astu (balanced) output terminals. In this case, of course, the matching section becomes an integral part of the feeder. A particularly convenient length of open-wire feeder is 84ft (25·6m), because such a length permits parallel tuning of the astu circuit on all bands from 3·5 to 28MHz with conveniently located coil taps in the astu coils for each band, or, where the alternative form of astu employing a three-gang 500pF/section variable coupling capacitor is used [4] the optimum loading condition can be achieved for each band. However, this is not a rigid feeder length requirement and almost any length that is mechanically convenient may be used. Since this type of feeder will always carry a standing wave, its characteristic impedance is unimportant, and sharp bends, if necessary, may be used without detriment to its efficiency. It is only when this type of feeder is correctly terminated by a resistive load equal to its characteristic impedance that such bends must be avoided.

Coaxial cable hf choke

Under certain conditions, either due to the inherent "unbalanced-to-balanced" effect caused by the direct connection of a coaxial feeder to the base of the (balanced) matching section, or to pick-up of energy radiated by the antenna, a current may flow on the *outside* of the coaxial *outer conductor*. This is an undesirable condition and may increase chances of tvi to nearby tv receivers. This effect may be considerably reduced, or eliminated, by winding the coaxial cable feeder into a coil of 8 to 10 turns about 6in in diameter immediately below the point of connection of the coaxial cable to the base of the matching section. The turns may be taped together or secured by nylon cord.

It is important, of course, that the junction of the coaxial cable to the matching section be made thoroughly water-proof by any of the accepted methods; binding with several layers of plastic insulating tape or self-amalgamating tape and then applying two or three coats of polyurethane varnish, or totally enclosing the end of the coaxial cable and the connections to the base of the matching section in a sealant such as epoxy resin.

References

[1], [2], [4] "ATU or astu?", by Louis Varney, G5RV. *Rad Com* August 1983.

[3] "HF antennas in theory and practice—a philosophical approach." Louis Varney, G5RV. *Rad Com* September 1981. □

Things to come—A cautionary tale

by LES MITCHELL, G3BHK*

OUR LITTLE GROUP of local ex-service G3 types often meets for a drink in the snug of the old coaching inn down by the riverside. Discussion ranges far and wide, but as one might expect revolves mainly around our wartime experiences and, of course, amateur radio.

Recently someone pointed out that he had not heard Bill on the bands for some time. Bill had obtained his licence immediately after the war and had spent every available moment chasing dx or chatting to his friends on 3·5MHz. Since he retired a few years ago he had spent even more time on the air, and it was very unusual not to hear him working on some band whenever one listened. When we compared notes we suddenly realized that no-one had heard Bill's signal for over six months.

"You live nearest to him," said Joe, "why don't you drop in and see what has happened. Let's hope he is not a silent key, but I am sure we would have heard something if he had passed on."

A few days later I knocked at Bill's door, rather worried that I might be faced by a tearful and grieving widow. The door swung open to reveal Bill with a big grin on his face, and looking fitter than I had ever seen him. Within a short time I was sitting in an armchair with a full glass in my hand and explaining why I had called.

"Well," said Bill, "it is a long story. You see just after I retired a relative of mine died and left me a useful sum of money. As you know, all my rigs were getting quite old, so I jumped at the chance to completely renew all my station equipment.

"First of all I purchased one of those Sky-Gain automatic aperiodic multi-band beams plus the computer controller. This array works on all bands and the computer turns the array to the maximum signal path without any effort on the part of the operator. I mounted this on my old 100ft tower and it was fantastic!

"Then I invested in the very latest transceiver, the Fuji Yama FJ 20,001, which covers all bands 1·8MHz to uhf with full legal power and no tuning whatsoever. To supplement this I also bought two computerized attachments—one which enables you to enter all the call prefixes of the countries you have worked already on each band, and then commands the transceiver to hunt each band in turn and only stops when it hears a new prefix. This unit also allows one to program automatic replies—callsign, signal reports, handle, location and requests to QSL etc. It had an additional program which made automatic calls to any of my friends' callsigns it heard on 3·5 and 7MHz. I had to keep these replies updated with the latest news: you know the sort of thing—the car has gone wrong again, I have just mown the lawn, the rheumatism is painful, the income tax people have overcharged me again, etc.

"The second computer unit was the printout attachment which automatically printed the log entries and produced fully-completed QSL cards. So you see I could just leave the rig on 24h/day and it would work the rare dx and also chat to my mates on 3·5MHz without me going near it except to add more printout paper and blank QSL cards. Apart from a trip to the post office every day to post the QSLs, it left me time for decorating, car cleaning, gardening and after-meal naps.

After it had been on the air continuously for about a month I discovered I had worked every dx station which existed, and even my friends on 3·5MHz were not replying to my calls—I expect they did not like the impersonal touch. Then I suddenly realized that this new rig had utterly and completely destroyed my interest in amateur radio. Even the walk to the post office was boring me, and the parcel post costs were also becoming a strain. So I then made the decision that after nearly 40 years on the air it was time to give up my hobby. I sold the rig, and with the money bought the xyl all the labour saving gadgets I could find—a washing machine, a microwave oven, a food processor, a dishwasher etc. Now she has as much spare time as me so we have taken up golf. It's very relaxing and gets us out in the fresh air. In fact we are spending more time together than we have done since we were courting!"

Bill and his xyl smiled at each other as she refilled the glasses. When I related this story to the others later there were sad faces all around. "But," I added, "Bill did tell me that he intends to renew his licence every year, so perhaps at some time in the future we shall hear him on again." But remembering just how those two smiled at each other I have my doubts. □

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